

TEST OF HIGH PERFORMANCE CAPACITORS*

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ABSTRACT

The long duration vortex flow spark gap we previously tested and reported¹ at the 15th power modulator symposium has been used to test high energy density, reped burst mode capacitors. Projected capacitor life based on voltage levels greater than design values is presented. In addition, the large number of test pulses at high coulomb transfer has yielded extensive electrode erosion data.

INTRODUCTION

The lifetime of high performance capacitors expressed in number of discharges depends on a large number of factors. Implicit in high performance is high energy density. Reported energy densities range from hundreds of joules per kilograms to just a few joules per kilograms. The determining factors are dielectric stress level, repetition rate, run duration, degree of energy reversal, voltage soak time, internal temperature, etc. The development of high energy pulse power systems at AERL led to design verification tests on high energy capacitor life particularly for those in the 3.8/1.9 μ fd 62.5 kV burst mode category. A capacitor test program utilizing the AERL switch-capacitor test facility was carried out to determine the limiting dielectric stress level of long lifetime repetitively pulsed capacitors. A severely restricted time schedule together with restraints imposed by the internal temperature rise of the capacitors made it necessary to expedite matters by testing at an elevated voltage. Empirically established relations between pulse life time and stress level exist which can be used to extrapolate the number of pulses that can be expected if the capacitor is used at or less than rated operating voltages. The test was performed with the aid of the spark gap switch that was reported on at the 15th power modulator symposium.^{**} The large amount of charge transferred through the switch yielded useful electrode erosion data for high current density repetitively pulsed high pressure air switches.

TEST FACILITY

The AERL switch-capacitor test facility is located in the Thumper PFN room which is a highly shielded area that was designed to house a multitude of pulse forming networks with its switch gear for energizing the Thumper laser. The facility is serviced with a 12 MW DC power supply. The system includes a capacitor filter bank, a series-parallel vacuum switch, an 18 henry and a 3.4 henry inductor and the usual crowbar and switchgear equipment. The power system is shown schematically in Fig. 1.

The capacitor test bed is contained in a tank filled with transformer oil. The tank houses the pair of capacitors that are under test, a spark gap switch, load resistor and trigger transformer. The

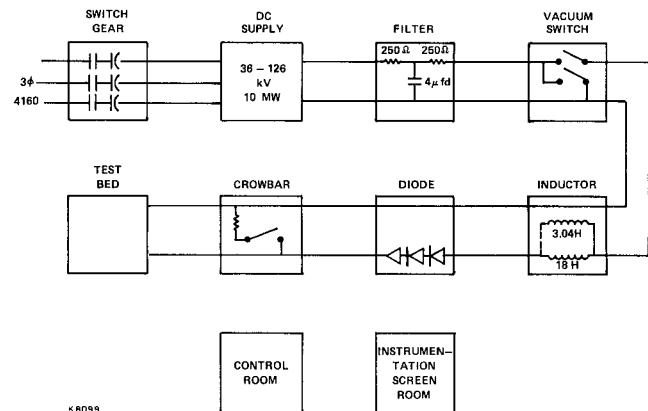
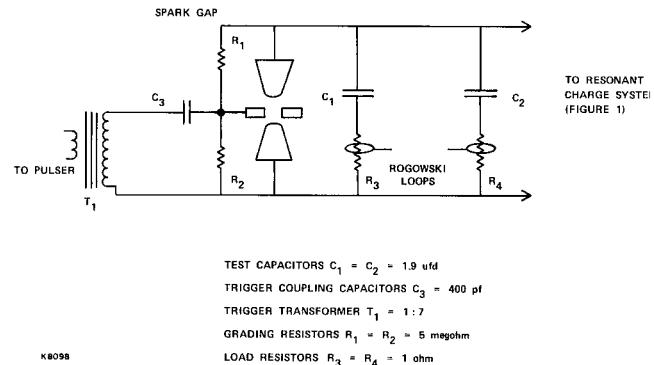


Fig. 1

test bed schematic as configured for the capacitor test is shown in Fig. 2. Two capacitors of two different manufacturers were tested simultaneously.



TEST CAPACITORS $C_1 = C_2 = 1.9 \mu$ fd
TRIGGER COUPLING CAPACITOR $C_3 = 400 \text{ pf}$
TRIGGER TRANSFORMER $T_1 = 1 : 7$
GRADING RESISTORS $R_1 = R_2 = 5 \text{ megohm}$
LOAD RESISTORS $R_3 = R_4 = 1 \text{ ohm}$

Fig. 2.

CAPACITORS

The two capacitors were both procured to the same specifications with the more pertinent factors listed in Table 1.

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TABLE 1

Capacitance	1.9 μ fd \pm 2.5 percent
Voltage	62.5 kV
Charging time	
Single Pulse	60 seconds
Repetitive	33 msec to 8 msec
Voltage reversal	
Single Pulse	< 50 percent
Repetitive	oscillatory discharge when crowbarred at 23.7 kV
Peak current	100 kA
Dissipation	< 0.3 percent at 1 kHz
Inductance	< 30 nH
Life	10 ⁵ shots

Both capacitors had a nominal energy density of 27 joules per kilogram and were virtually equal dimensionally.

The normal stress level of one capacitor was 2440 volts per mil while the other vendor declined to disclose his capacitor stress level or any other information regarding the internal design factors.

TEST CONFIGURATION

To test the capacitors of both manufacturers in a fair manner, it was decided that they had to be tested simultaneously. For this reason, a test stand utilizing two separate discharge circuits, one for each capacitor with a common switch, was assembled. Separate instrumentation allowed both discharge currents to be evaluated and compared.

Both capacitors, the switch and the two load resistors were immersed in the common tank of transformer oil together with the trigger transformer and trigger coupling capacitor. The resistance value selected was such that in conjunction with the circuit inductance the capacitor voltage reversal was between 0 to 20 percent.

Each load resistor had to dissipate more than 500 kW or 1 MJ in each test burst. Therefore, the copper sulfate electrolyte, which formed the resistor, was continuously circulated through a heat exchanger located outside of the test tank. The repetitively pulsed spark gap was of the type described elsewhere, but modified to operate over the voltage range of interest by reducing the electrode spacing.

INSTRUMENTATION

Rogowski coils encircling each resistor were used to measure the discharge current. The voltage was measured with a conventional voltage divider. The discharge current pulses were fed to a pair of Tektronix digitizers which allowed the waveforms of groups of 8 pulses from each capacitor to be measured and recorded photographically. The current pulses were integrated and fed to a chart recorder so that the energy level of each capacitor discharge could be compared pulse by pulse for each pulse throughout the entire burst. The chart recorder included capacitor charge voltage, trigger pulses and input line current. An electronic counter kept track of the number of pulses accumulated.

TEST PROCEDURE

The power supply was adjusted so that the resonant charge voltage was 78 kV. The test was carried out in bursts of 200 pulses at a pulse rate of 100 pps. The duty cycle allowed on the capacitors

restricted the operation to one burst of 200 pulses each 3.5 min. The resistor, which was an aqueous solution of copper sulfate, was continuously circulated through a heat exchanger. In this manner the energy was almost completely removed from the oil tank.

Since the load resistor was connected to the high potential side of the circuit, it was not feasible to use the usual Pearson Current transformers. A pair of Rogowski coils were fabricated and one installed around each resistor. The output of the associated integrators were integrated once and sent to the digitizers and after a second integration sent to the chart recorder.

The electrodes in the switch were fitted with removable elements so that accurate weighing before and after could be made in order that electrode erosion could be determined. The electrode material was a sintered combination of copper and tungsten.

TEST RESULTS

Prior to the main body of bursts, 2000 pulses were accumulated in the process of check out, calibration, etc. The preliminary tests were done at 63 kV and 40 pps.

The main group of bursts was at 100 pps in bursts of 200 pulses every 3.5 minutes. All of the discharge pulses were recorded on the charge recorder and periodically on the digitizer. Since the effort was based in particular on capacitor performance the switch was operated in a very conservative manner with the result that an occasional misfire occurred. The actual discharge pulses were counted electronically so that a reliable count of the actual pulses was obtained in spite of the occasional misfires. A typical group of 8 consecutive pulses is shown in Fig. 3.

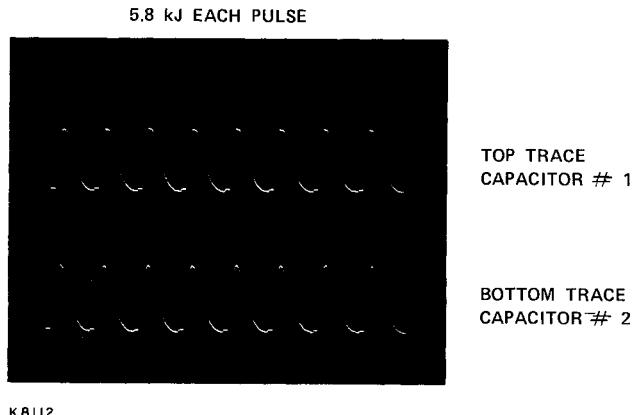


Fig. 3

At 31677 pulses the load resistor housing failed and since the schedule did not permit repair and projected capacitor life exceeded specification, the test was terminated.

CAPACITOR LIFE SCALING

At the rated voltage of 62.5 kV the dielectric stress is 2400 V mil⁻¹ and the rated life is 10⁵ shots. Since the test accumulated 3.2 x 10⁴ pulses at 78 kV a projected life at 62.5 kV can be determined.

Both capacitors withstood 31677 pulses at an elevated operating voltage. It was felt that the number of accumulated pulses was large enough to warrant extrapolation of life at normal voltages and to make a prediction of the operating stress level that would allow a higher than specified number of pulses.

Assuming that the life-stress function is

$$\frac{L_2}{L_1} = \frac{S_1}{S_2}^{7.3}$$

the projected life at 62.5 kV is $> 1.5 \times 10^5$ pulses because there were no failures.

If, for example, 10^8 pulses are to be achieved then the same function can be used to determine a working stress of 10^3 V mil $^{-1}$.

Assuming that the 7.3 power law holds, Table 2 gives the maximum tolerable dielectric stress level for a capacitor operating in this type of mode.

TABLE 2
LIFE VS. DIELECTRIC STRESS

Life Pulses	Volts/Mill	Joules/lb
10^4	3290	22
10^5	2400	11.8
10^6	1750	6.3
10^7	1280	3.3
10^8	930	1.8
10^9	679	0.9

ENERGY DENSITY SCALING

In the Exxon/Avco tests with Maxwell capacitors it was concluded that

$$E_b = \left(\frac{S}{700 \text{ V/mil}} \right)^2 \times 1 \text{ J/lb}^{-1}$$

Therefore, when $S = 1000 \text{ V mil}^{-1}$, the energy density for 10^8 pulse capacitor must be at least 2 J/lb.

CONCLUSIONS

In the first 2000 pulses the charge transfer through the switch was $Q_1 = 3.8 \times 10^{-6} \times 63 \times 10^3 \times 2 \times 10^3 = 478$ coulomb. In the remaining 29677 pulses the coulomb transfer was $Q_2 = 3.8 \times 78 \times 10^{-6} \times 10^3 \times 29.7 \times 10^3 = 8800$ coulomb. There was a total of 31,677 pulses with overshoots ranging from 2 percent to 10 percent with an estimated mean of 5 percent. The specified life of 10^5 pulses when operated at normal voltage is reasonable to expect.

Although it was not the main goal in this test series the significant coulomb transfer allows a good erosion determination.

	CATHODE	ANODE
Initial Weight	359.3 g	355.5
Final Weight	355.0 g	351.4
Change in Weight	4.3 g	4.1 g
Coulomb Transfer	9281 coulomb	9281 coulomb
Erosion Rate	463 $\mu\text{g coulomb}^{-1}$	442 $\mu\text{g coulomb}^{-1}$

REFERENCES

1. High Power Spark Gap Test Result, 1982 Pulse Power Modulator Symposium, R. Limpaecher, R. Schneider.